COASTAL HERITAGE

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Rising Tide

Will Climate Change Drown Coastal Wetlands?

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ON THE COVER: *Along the coast of the U.S. Southeast, many older homes, like this one in Beaufort County, are built dangerously low to the ground near salt marshes.*
PHOTO/WADE SPEES

Andrea Hougham, a University of South Carolina graduate student in geology, examines a marsh die-off site in North Inlet.
PHOTO/WADE SPEES

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S.C. Sea Grant Consortium
287 Meeting Street
Charleston, S.C. 29401
phone: (843) 727-2078
e-mail: Annette.Dunmeyer@scseagrant.org

Executive Director
M. Richard DeVoe

Director of Communications
Susan Ferris Hill

Editor
John H. Tibbetts

Art Director
Carl Turner

ON THE EDGE. ***People who invest in properties near salt marshes, like this one on Shem Creek in Mt. Pleasant, should know their risks from flooding.*** PHOTO/WADE SPEES

Rising Tide

Will Climate Change Drown Coastal Wetlands?

By John H. Tibbetts

In the 1960s, land next to a southern salt marsh was dirt-cheap, disdained as flood-prone, sweltering, and mosquito ridden, sometimes smelling like rotten eggs at low tide. *Who wants to buy that?*

But by the mid-1970s, federal flood insurance had slashed the financial risk for many coastal property owners and mortgage lenders. Soon people weren't as troubled by the flood threat—or mosquitoes or an occasional stink. *Isn't it beautiful?*

Now salt-marsh frontage can cost as much as a beach parcel. "In the last few years, barrier islands and coastlines have filled up with development," says Stanley R. Riggs, a coastal geologist at East Carolina University in Greenville, North Carolina. "So estuaries have become the next big investment area."

Investors are snatching up lower reaches of the lowcountry—acre upon acre of temporarily solid ground sloping toward the pluff mud of South Carolina's coastal wetlands. Developers are constructing single-family houses, condominiums, restaurants, and marinas in places just above high tide, transforming the state's salt-marsh edges.

During recent hurricanes, coastal residents learned, once again, that living near the ocean is dangerous. But it'll get more so in the future.

"Some South Carolina coastal wetlands will likely drown within the next 50 years," says James T. Morris, a marine scientist and director of the University of South Carolina Belle W. Baruch Institute. "In most cases, we're talking about a period longer than a 30-year mortgage before people see huge changes. But there should be concern now. People who invest in these vulnerable coastal properties really should know their risks."

Rising sea level is already making some salt marshes migrate inland, exposing coastal structures to more flooding. Property owners who build walls to prevent erosion along tidal creeks can increase erosion in downstream areas.

Today some salt marshes are drowning, and so coastlines are losing wildlife habitat and nursery grounds for commercially important fisheries such as shrimp and blue crab. Salt water is moving up some streams and rivers, damaging freshwater swamps and creating "ghost forests" of dead trees.

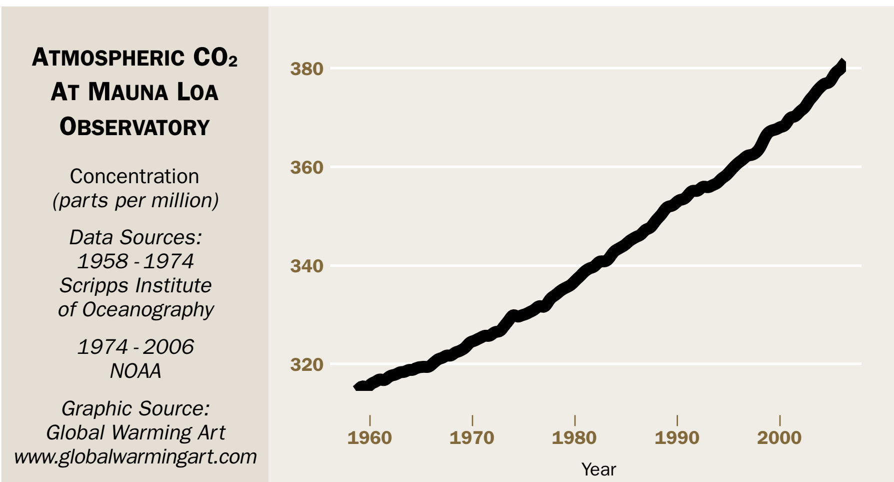
We'll see even more of all this in the future. There is a growing scientific consensus that global sea level will rise faster because of climate change.

For the past 18,000 years, since the end of the last Ice Age, global sea level has gone up about 360 feet in fits and starts. What is so different about today is that human activities are a major driver of global warming, although natural variability also has a role, according to leading climate scientists.

In June 2006, a special committee of the National Academies of Science pointed out that there are "multiple lines of evidence for the conclusion that climatic warming is occurring in response to human activities."

Dozens of peer-reviewed studies in prestigious journals have documented the crucial role of carbon dioxide and other greenhouse gases in heating the planet. Increased greenhouse gases add to the layer in the atmosphere that traps some of the sun's heat, further warming the Earth. Consensus reports by climate scientists and scientific organizations predict that over the next century climate change will almost certainly gain momentum.

Carbon-dioxide levels in the atmosphere have increased from 280 parts per million before the industrial revolution (which began about 1750) to 380 parts per million today. These concentrations will continue to rise for some time, potentially causing abrupt ecological disruptions.



Rising carbon-dioxide levels in the atmosphere are adding to the layer of gases that trap some of the sun's heat, further warming the Earth.

A hotter climate drives up global sea level by expanding seawater; this is called thermal expansion. Melting land-based ice sheets and land-based glaciers in Antarctica and Greenland send pulses of freshwater into oceans.

Climatologists are trying to estimate which threshold of atmospheric carbon dioxide would spawn accelerated global warming and cause environmental and social catastrophes. How much carbon dioxide would, for example, set off a chain reaction of warming that would drive up sea levels and drown coastal cities? Some scientists have argued that 500 parts per million would push the world into real trouble; others say 450; still others say 400.

Numerous studies have estimated—based on computer models—how high and how quickly sea level could go up. In 2001, the Intergovernmental Panel on Climate Change (IPCC) noted that it's possible, though very unlikely, that global sea level could rise by as much as three feet by 2100. The IPCC's next comprehensive report, due in 2007, is expected to lower the worst-case scenario.

But these estimates exclude Antarctica and Greenland's future contributions to sea level rise, says Greg Carbone, a USC geographer. During the past year, scientists have noted that polar ice sheets are melting much faster than anticipated. Some researchers fear that this and other rapid changes could potentially lead to a sea-level rise of four to six feet by 2100.

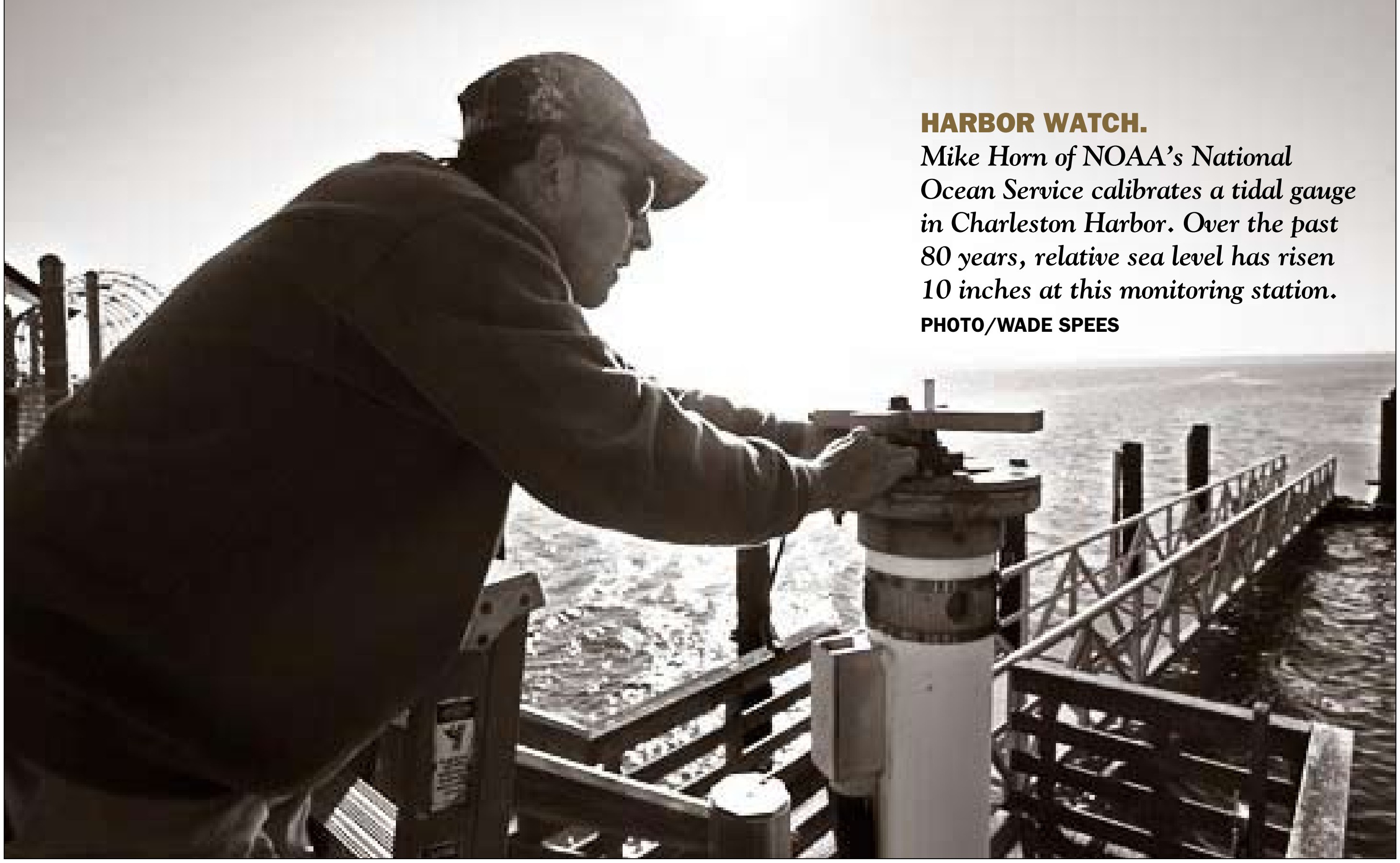
Carbon dioxide lingers in the atmosphere, continuing to warm the planet for hundreds of years after it's put there. Our children, grandchildren, and great-grandchildren, therefore, will live with the consequences of past actions.

The sea also has a temperature lag. As greenhouse-gas concentrations rise in the Earth's atmosphere, the planet's surface—including the ocean's surface layer—is the first to get warmer. Over time, though, heat sinks into lower and lower ocean layers. Warmth falls into the sea depths like a fresh corpse in *The Sopranos*. And as the deeper ocean gets hotter, water there expands and inexorably raises global sea level.

The lower ocean layers are warming —and will continue to warm—in part because of pollution that industrial society put into the atmosphere decades ago. As a result, sea level will continue rising because of the built-in momentum of the natural system. And sea level increases would almost certainly continue long after 2100 unless emissions are greatly reduced.

"There's the perception that if global warming becomes bad enough, we can institute a few policies fairly quickly," says Gerald Meehl, a climatologist at the National Center for Atmospheric Research in Boulder, Colorado. "But it's not that easy. Once the ocean starts warming up, it will work its way down into deeper water, and as you reach greater depth, you have thermal expansion and a relentless sea level rise just from what we've already put into the system."

Rising sea level, however, could be slowed if the global community would sharply reduce greenhouse-gas emissions. "We could begin by cutting (global greenhouse-gas) emissions by 20 percent over the next 10 to 15 years," says Meehl, "and by the end of the century we'd need to cut emissions by 80 percent. This would be very difficult, but the longer we wait to do something, the harder it gets."



HARBOR WATCH.
Mike Horn of NOAA's National Ocean Service calibrates a tidal gauge in Charleston Harbor. Over the past 80 years, relative sea level has risen 10 inches at this monitoring station.
PHOTO/WADE SPEES

DIFFERENT SEA LEVELS IN DIFFERENT PLACES

As a rule of thumb, a one-inch rise in sea level translates into 100 inches of shoreline retreat, all other factors being equal. Still, things are rarely equal along the coast. Each region's shoreline is unique. The ocean rises or falls at various rates in various places.

This is called "relative sea level"—the combination of global sea level and the many finer-scale influences, natural and manmade, which significantly raise or lower coastlines. New Orleans, for instance, has a faster relative sea level rise than does Charleston. New England has a faster one than southeast Florida. Some coastal regions, therefore, face more immediate threats of flooding and erosion.

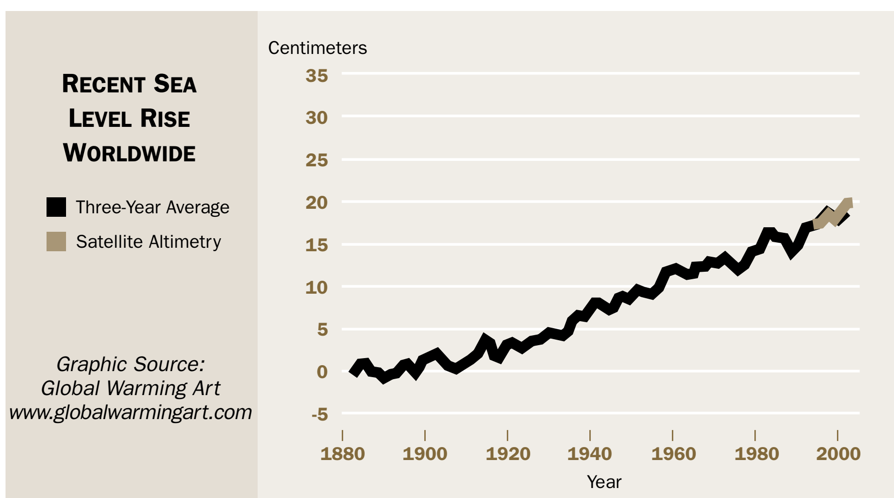
Coastlines can sink—or subside—for a number of reasons. Some subside mostly because of shifting geological faults; others subside mostly because of intensive pumping of groundwater and fossil fuels.

River dams, which trap sediments, rob coastal wetlands of marsh-creating materials, and then coastlines sink beneath the sea. Parts of the Louisiana and California coasts have lost coastal land because of dams on rivers running to the coast.

Dredging waterways takes sediments from one coastal location and often gives them to another, or the sediments get pushed out to sea and lost to the coast for good.

River levees often disrupt where river-borne sediments go. Levees, of course, are designed to prevent flooding of homes and businesses along rivers and estuaries, but levees also stop the flooding that would send sediments to coastal marshes. Levees along the Mississippi River are largely responsible for the massive land loss over the past 75 years in Louisiana.

Numerous landowners have built bulkheads, which are vertical wooden structures intended to control erosion along tidal creeks and bayfronts. Other landowners have installed revetments, which comprise large rocks or boulders intended to hold the tidal shoreline in place. Bulkheads and revetments prevent



This figure illustrates the three-year averaged sea level at 23 tide-gauge sites around the world since the 1880s.

marshes from migrating naturally inland as relative sea level rises. A bulkhead or revetment can also create a straightened creek channel, which makes currents run faster, narrower, and deeper, preventing some sediments from settling in nearby wetlands.

Over the past 80 years, relative sea level has risen 10 inches at Charleston harbor's shoreline, measured by a NOAA monitoring station there. That's about 50 percent faster than the global average. Why? Charleston's sediments are naturally compacting—squeezed under their own weight. Over thousands of years, rainfall has eroded upland areas and carried sediments down the Ashley and Cooper rivers, settling to form coastal wetlands. As these loose sediments compact, the coast slowly sinks.

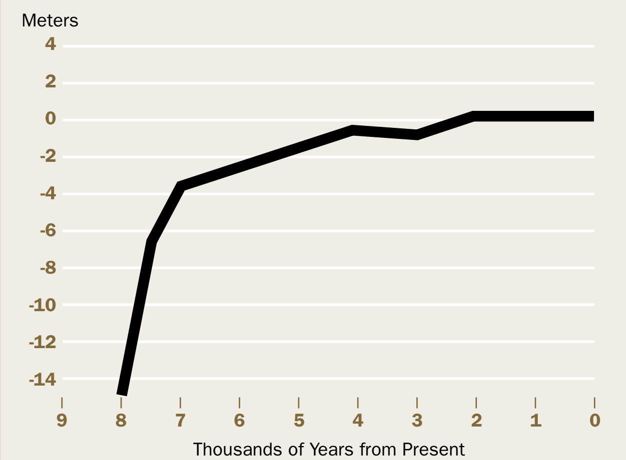
S. Jeffress Williams, a coastal marine geologist at the U.S. Geological Survey (USGS) in Woods Hole, Massachusetts, says that Charleston's relative sea-level rise has two roughly equal causes: naturally occurring subsidence and various global influences. Over the past century, much of the U.S. Atlantic coast's sea level has gone up about the same amount as Charleston's—about an inch per decade—though there are many local exceptions.

During the past 4,000 years, many of South Carolina's salt marshes have apparently adapted to rising sea level. Some wetlands have escaped constant inundation by naturally migrating inland, taking over forest edges and other upland areas. Salt marshes can't stay healthy when flooded constantly. Marsh grasses die from stress, the sediments disperse, and then the wetland sinks, becoming open water.

Now many U.S. salt marshes are already drowning under a one-two punch of rising global sea level and regional losses of sediments from development.

"With the damming of rivers, with dredging parts of the coast, with building revetments and bulkheads, we are cutting off the supply of sediment that gets to the wetlands," says Williams. "For the next 50 to 100 years, will we be able to get enough sediment to maintain the wetlands' elevation above sea level? That's really the important question."

Sea Level Change Over the Past 9,000 Years



Graphic Source: Global Warming Art www.globalwarmingart.com

After the end of the Ice Age, sea level rose dramatically, but then it leveled out about 4,000 years ago. In coming centuries, sea level is expected to rise more quickly again because of global warming.

BY MID-CENTURY

During the 1990s, global mean sea level—and sea level along the Atlantic coast—rose faster than at any time during the twentieth century.

From 1900 to 1992, global mean sea level went up by about eight inches, based on tide-gauge measurements. That's slightly more than the thickness of a dime per year. Which doesn't seem like much. But, over time, the inches have added up.

In 1992, scientists began gathering satellite data of sea level in the middle of the oceans as well as along coastlines. These measurements showed that global mean sea level rose about 50 percent faster from 1993 to 2003 than during the previous nine decades. This acceleration, however, doesn't necessarily signal a long-term trend.

"Ten years is too short a period to extrapolate anything in the future," says Tony Sturges, an oceanographer at Florida State University.

Global sea level will continue to rise during this century, scientists agree. But over the shorter-term—a decade or two—relative sea level in some locations can go up or down.

Relative sea level along the U.S. East Coast is altered by events lasting from a few days to decades: cyclical atmospheric patterns such as El Niño and La Niña, changes in Atlantic Ocean circulation and water density, wind effects, changes in ocean evaporation and precipitation, river runoff and major floods, seasonal water balances among the different oceans, and large hurricanes and nor'easters.

"Relative sea level bounces around a lot from year to year," says Morris. "It's not this well-behaved curve that most people think it is. It's a jagged line when you plot it."

Influenced by a mysterious cycle, U.S. Atlantic coast sea level rises for five to 10 years and then falls for five to 10 years. "A strange class of waves"—called Rossby waves—drives this cycle, says Sturges. "The Rossby waves are very slow, large, and in deep water," moving westerly from the eastern side of the Atlantic to the U.S. East Coast. "They build up over a period of years and hit the East Coast."

And then, when Rossby waves disappear, relative sea level falls along the Atlantic shoreline. So what causes the Rossby waves? No one knows.

The moon, moreover, has a wobble in its orbit. This wobble doesn't affect relative sea level, but it does drive a cycle in tidal ranges. It pushes tides higher and higher for nine years and then increasingly lower for nine years. Every 18.6 years, the "lunar-nodal cycle" adds five centimeters (two inches) to high tides along the Atlantic coast.

"Five centimeters doesn't sound like very much, but actually (*continued on page 8*)

Do salt marshes function as storm surge buffers?

Coastal marshes and wetlands help protect the mainland from hurricane flooding, right? Well, maybe. Some scientists say there haven't been adequate studies on whether or not vegetated areas such as salt marshes do, in fact, buffer the shoreline from storm surges.

Now, preliminary results from a study of Louisiana wetlands and Hurricane Katrina seem to show that these ecosystems can have some protective effect.

In certain circumstances, a wetland's vegetation can help brake a storm surge, says Rick Luettich, a coastal oceanographer at the University of North Carolina at Chapel Hill. "The vegetation fabric can slow the storm surge down, depending on what the vegetation is and its height in relation to the water depth."

Salt-marsh grasses such as *Spartina alterniflora* might not provide much buffering if a major hurricane hit at high tide since the marsh grasses might become quickly submerged, allowing the surge to wash over them and strike the mainland at full force.

However, healthy coastal wetlands can hold large amounts of sediment instead of just water. "When there's a wetland, it tends to enhance sedimentation and decrease open water areas," says Luettich. "This can reduce the amount of water that's readily available to flood the mainland."

Salt marshes and other types of coastal vegetation "cause land to accumulate, and that can have a significant effect (on buffering a storm surge) in much the same way a barrier island does," he says.

Luettich and his colleagues studied a huge wetland area called the Biloxi marshes southeast of New Orleans. They used computer models to compare Katrina's storm surge and the flooding that could have occurred if those marshes were replaced with open water.

Without the marshes there, Katrina's storm surge would have been roughly a meter and a half (about four and a half feet) higher in areas south of New Orleans along the eastern shores of Plaquemines and St. Bernard parishes.

"Achieving the maximum hurricane protection requires more than just moving sediment down to wetlands and making more marshlands," says Luettich. "Ideally, you might design wetlands to sustain sturdy vegetation types such as shrubs or cypress trees, creating marsh islands, which provide better buffers than grasses alone. Understanding which landscape features buy you the most in terms of storm protection is really important in designing a comprehensive system in flood-prone areas."

PHOTOS/WADE SPEES

Hurricane Katrina, meanwhile, showed how estuaries and bays—geographic dimples along shorelines—heighten flooding. "Bays and estuaries are more susceptible to an elevated storm surge because they have a funneling effect," says Luettich.

Barrier islands are the mainland's first line of defense, taking the first, heaviest blow of a storm surge. When a surge strikes a "straight" coastline such as a barrier island head on, ocean waves batter oceanfront homes and then push inland toward the island's high-ground backbone. Yet the storm surge also spreads out sideways in both directions along the shoreline. This shape shifting draws down some of the surge's destructive power as it approaches the island's backside.

By contrast, when the hurricane's winds drive water into an estuary such as Charleston Harbor or Port Royal Sound, it is trapped between two converging shorelines and has nowhere to go but up. Katrina's surge approached 30 feet in some locations along the Gulf Coast.

it's huge," says Morris. "In intertidal wetlands, a change in five centimeters in tidal amplitude translates into a much larger change in the flooding frequency of marshes."

Remember, when salt marshes are flooded continuously, they drown. The high-tide extremes of this cycle most recently occurred in 2000, and are predicted to reoccur in 2018, 2037, and 2055.

During the 1990s, several influences came together to drive extensive flooding along the East Coast. Global sea level rose faster than usual. Rossby waves were pushing westerly, driving up relative sea level along the East Coast. High tides were higher because of the bump in the moon's orbit. In addition, wetland-building sediments had been disappearing from many East Coast estuaries because of dams, dredging, and other urbanized development.

As a result of all these influences, salt marshes were submerged longer and more often during the late 1990s. Some wetlands died as a result, says Morris. "Those wetland losses were not just a coincidence."

Yet, surprisingly, salt marshes prospered at the North Inlet-Winyah Bay National Estuarine Research Reserve in Georgetown County. Morris found that coastal wetlands there thrived during the 1990s.

At the highest elevations of the North Inlet marsh, the plants initially were stressed because of too little flooding. But with the rise in sea level and tidal range during the late 1990s, the marsh plants grew thicker and taller. Larger plant surfaces captured additional suspended sediment as higher tides and rising relative seas flowed over the marsh.

Having trapped more sediment, the marsh plants had greater amounts of mud to grow in. So the marshes, in response to greater flooding, showed greater plant productivity. This feedback mechanism among the plants, greater flooding, and increased sedimentation is how the marsh normally keeps up with rising sea level.

But can the marsh continue to keep pace?

Not necessarily, says Morris. If the rate of sea level rise crosses a certain threshold, then the marsh can't keep up and will drown. When will that threshold be crossed?

By the 2050s, most likely.

Global sea-level rise, Rossby waves, manmade disruptions to sediment supplies, natural shoreline sinking, cyclical atmospheric changes, major hurricanes and nor'easters, and the lunar-nodal cycle that causes especially high tides—a number of these and other pressures will coalesce, probably by mid-century, to overwhelm many South Carolina coastal marshes, says Morris.

Coastal residents might not realize that the state's saltwater wetlands are in trouble until it's too late. By mid-century, many marshes will continue looking healthy—right up to the moment when abruptly, with no visible warning, they start to disappear.

"Salt marshes love it when sea levels are high—up to a point," says Morris. "They look their best—in terms of plant productivity and health—right at the threshold of high water, but once they go over that threshold, they drown."

North Inlet marshes are somewhat sediment-poor compared to many others in South Carolina. Fed by comparatively modest riverflow, North Inlet wetlands might be among the first in South Carolina to start drowning by mid-century. Other estuaries, sediment-rich, would be expected to keep their salt marshes longer. "There will be a lot of variation from estuary to estuary," says Morris.

Coastal wetlands, if they migrate inland quickly enough, might escape drowning for a time. But they'd bump into manmade bulkheads and revetments protecting higher ground. Marinas, restaurants, and homeowners commonly install bulkheads or revetments to protect buildings and land when tidal creeks erode higher ground. But such walls will eventually cause more wetlands to be squeezed to death.

A similar process occurs on the beachfront, where seawalls allow waves and currents to scour out the sand in front of the wall. As a result, the sandy beach eventually disappears.

"It's sort of the same debate that we've had about beaches" and seawalls, says Debra Hernandez, a former state coastal-zone manager and now a coastal planning consultant.

In 1988, the state of South Carolina banned construction of new seawalls and eventually the repair of most old ones as part of the S.C. Beachfront Management Act.

Along tidal creeks, however, South Carolina manages new erosion-control walls much differently than it does along beaches. The state allows construction of new bulkheads and revetments, which are intended to prevent erosion of high ground from tidal creeks.

"In places where there are houses, bulkheads, and revetments protecting the shoreline, these (developments) prevent a natural migration of the shoreline, and then you just get a hardened coast," says Williams of USGS.

S. JEFFRESS WILLIAMS

"With the damming of rivers, with dredging parts of the coast, with building revetments and bulkheads, we are cutting off the supply of sediment that gets to the wetlands."

WHAT COULD HAPPEN IN 20 YEARS?

Peter Howd lives in a house a block and a half from the estuary of Tampa Bay, Florida. His home's first floor is eight feet above sea level.

"It's not a safe place," says Howd, an oceanographer who conducts shoreline research for USGS in St. Petersburg. "My concern is about a combination of sea-level rise and hurricanes. If we get hit by a category 4 storm, my house will be under water." Howd is 50 years old. "I don't want to retire in this location with that kind of worry."

Today, thousands of people live in older homes built low to the ground near

BALANCING ACT. *University of South Carolina (USC) graduate student Andrea Hougham checks groundwater monitoring pipes in a North Inlet salt marsh. S.C. Sea Grant Consortium scientists Alicia Wilson and James T. Morris, both of USC, are studying whether drought alters the salinity of groundwater beneath salt marshes. An increase in groundwater salinity might kill salt-marsh vegetation, allowing sediments to disperse and eventually drowning marshes. Computer models show that climate change will likely alter precipitation patterns in the U.S. Southeast, potentially causing longer, more intense droughts.*
PHOTO/WADE SPEES

salt marshes and tidal creeks in the southeastern United States. Starting in the 1970s, most coastal communities began joining the National Flood Insurance Program, which requires new and substantially remodeled flood-prone structures to be elevated on pilings or tall foundations. Homes that are elevated have a better chance of surviving storm surges.

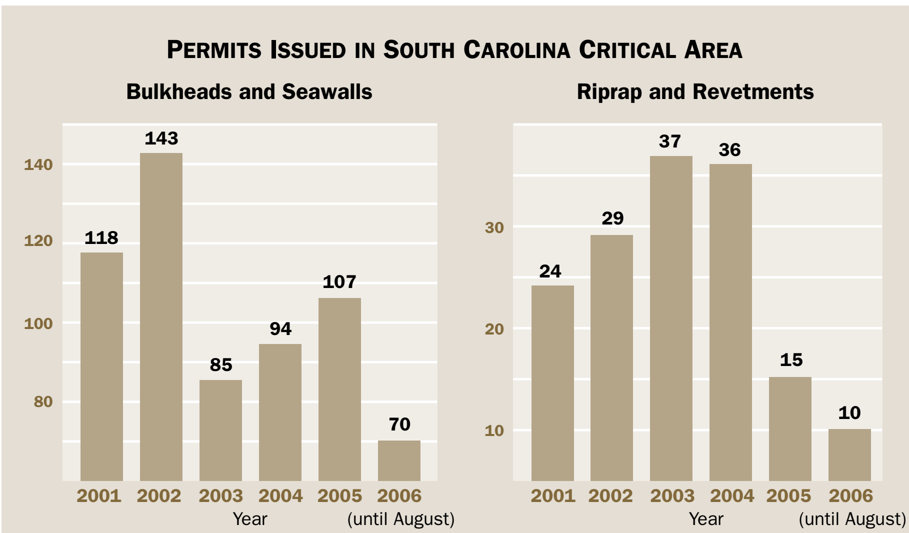
A typical older home located next to a South Carolina salt marsh has an occupied first floor less than 10 feet above mean high tide. Many of these homes are on sea islands and other vulnerable locations.

"Sooner or later, a surge will come through," says Tim Kana, president of CS&E, a coastal engineering firm in Columbia, South Carolina. "Many people have been lucky so far."

Even a modest rise in relative sea level could create higher storm surges under some conditions. What if Charleston Harbor's relative sea level went up by, say, four inches over the next 20 years? That would be about 25 percent faster than the rate of 1993-2003.

Four extra inches of relative sea level rise could cause more erosion in some locations and somewhat more flooding during high tides and coastal storms.

"A higher sea level gives a coastal storm a head start," Howd says. "Any time water level is elevated for whatever reason, it creates a cumulative impact."



Since 2001, South Carolina coastal regulators have issued more than 760 permits allowing property owners to build hard erosion-control structures along tidal creeks, bay frontage, and behind barrier islands. Source: SCDHEC-OCRM.

THE HEALTH OF SOUTH CAROLINA'S COASTAL WETLANDS

Many of South Carolina's salt marshes appear vigorous and healthy, fed by muddy rivers, which carry vast amounts of sediments downstream to the coast. But it's difficult to say, with any certainty, how the state's salt marshes are responding to relative sea level rise. That's partly because today's changes are slow.

"The marsh begins creeping up into places where it hasn't been before," explains Paul Gayes, a marine scientist at Coastal Carolina University. "It's a chronic, yet very subtle process. Four times a year, an upland area will get flooded because of winds added to the tide. Then a decade later it's being flooded five times a year. It's a creeping process that eventually causes a change in vegetation" from upland to salt marsh.

This retreating process has been a natural one over thousands of years, though it's expected to speed up sometime in the future.

South Carolina's saltwater wetlands are probably "in relatively good shape," says Williams of USGS, compared with those of many other regions such as coastal Louisiana, parts of Florida, and sections of the Chesapeake Bay.

North Carolina is facing dramatic losses of upland areas adjacent to coastal wetlands. Salt marshes are migrating rapidly along the inland edges of North Carolina's unique, fragile coastal sounds, Albermarle and Pamlico. The abrupt migration is caused by a combination of hurricane surges in the coastal sounds and sea-level rise, says Stanley R. Riggs of East Carolina University.

"We see erosion—oceanfront and estuarine—all over" coastal North Carolina, says Spencer Rogers, a coastal hazards specialist with the North Carolina Sea Grant Program.

Some tidal creeks in South Carolina, meanwhile, are cutting into upland areas. From 2001 through 2006, regulators at the Department of Health and Environmental Control-Office of Ocean and Coastal Resource Management (OCRM) issued more than 760 permits allowing property owners to build bulkheads, seawalls, riprap, and revetments along tidal creeks, bay frontage, and in areas behind barrier islands.

State officials say they consider issuing a permit for a bulkhead or revetment along a tidal creek only when the waterway is eroding high land. A landowner would not receive a permit if salt-marsh vegetation has migrated into an upland area and there is no evidence of tidal-creek erosion.

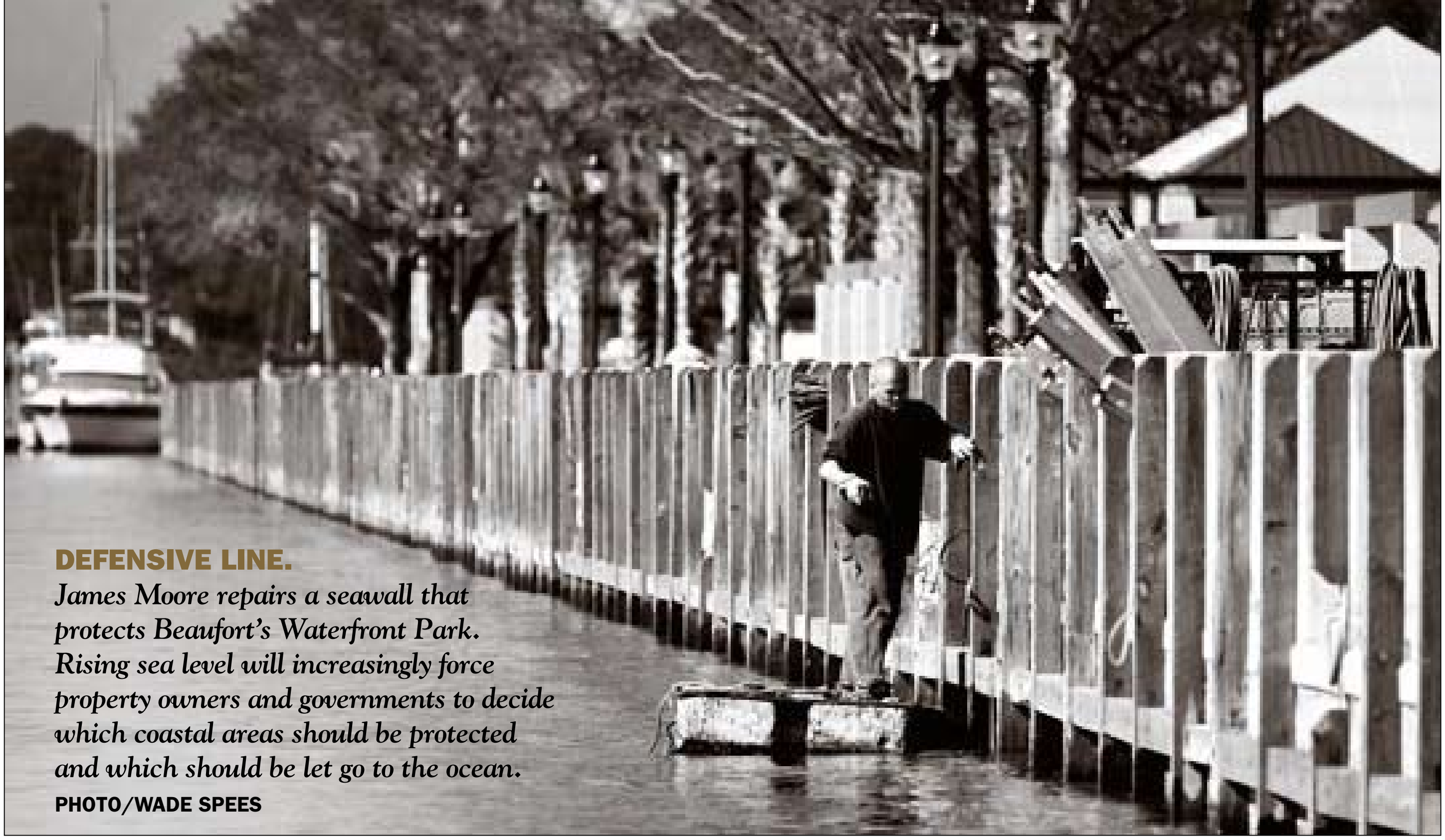
Is tidal-creek erosion in South Carolina caused by rising relative sea-level rise or something else? Boat wakes? Changing land uses?

"It could be all of the above in some cases," says Barbara Neale, director of the Regulatory Division of OCRM. It's difficult to sort out the causes of erosion along a tidal-creek bank. "Creeks are dynamic systems, and a creek channel could be changing direction naturally," cutting a new path through high land, she says, but "now people living there are in the way."

"MINI-MISSISSIPPI RIVER SITUATIONS"

Louisiana loses 34 square miles of wetlands to the Gulf of Mexico every year. Could South Carolina lose salt marshes in a similarly rapid fashion?

"What's happening to Louisiana is a forerunner of what could eventually



DEFENSIVE LINE.
James Moore repairs a seawall that protects Beaufort's Waterfront Park. Rising sea level will increasingly force property owners and governments to decide which coastal areas should be protected and which should be let go to the ocean.
PHOTO/WADE SPEES

happen to the U.S. East Coast because of relative sea-level rise," says Abby Sallenger, an oceanographer with the USGS Center for Coastal and Watershed Studies in St. Petersburg, Florida.

Coastal Louisiana's salt marshes have been drowning for decades mostly because they've lost valuable sediments to navigation dredging, river levees, dams, and other projects.

For thousands of years, the Mississippi River and its tributaries flowed down to the Mississippi Delta, where immense floods periodically burst over the riverbanks, allowing huge quantities of silt to settle and nourish wetlands. The river and its sediments created millions of acres of South Louisiana's delta before the twentieth century.

But for the past 70 years, the Mississippi River's flow has been diverted or rerouted through narrow navigation corridors kept in place by 2,000 miles of earthen, rock, and concrete levees. Straight-jacketed and walled off from the floodplains, the river can no longer provide silt to the delta, silt needed to nourish marshes.

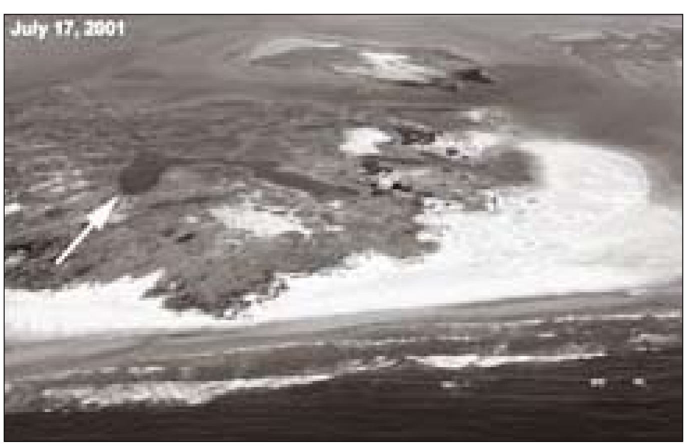
The levees and offshore jetties, plus dredging for navigation, have created a deeper, narrower, faster river channel that races offshore. The river annually shoots about 120 million tons of sediment into the Gulf of Mexico.

Gulf currents push sediments off the continental shelf, where they are lost to the marsh system.

Mississippi River levees have stopped catastrophic spring floods in the delta, but at an environmental cost, robbing life-giving silt from south Louisiana ecosystems. That's why coastal wetlands are disappearing beneath the waters of the Gulf of Mexico.

Coastal Louisiana's relative sea level has changed rapidly—it's about three feet higher than a century ago. Approximately 80 percent of this relative sea level-rise has been caused by subsidence, a large

Hurricane Katrina nearly wiped out the Chandeleur Islands southeast of New Orleans, as shown in these before-and-after images.
PHOTOS/U.S. GEOLOGICAL SURVEY



portion of which is due to navigation projects that divert Mississippi River watershed sediments; about 20 percent is caused by global influences, including climate change, says Williams.

Braxton Davis, director of the Science and Policy Division at OCRM, worries that South Carolina could, over time, see construction of numerous erosion-control walls built along much of the length of some tidal creeks.

South Carolina could eventually face "mini-Mississippi River situations," says Davis. That is, miles of bulkheads and revetments along tidal creeks could change currents and push wetland-building sediments farther into the coastal ocean, where they would be unavailable to salt marshes. This would cause more rapid erosion downstream.

The longer-term problem is that bulkheads and revetments along tidal creeks prevent salt marshes from naturally migrating as sea level rises.

In 2006, an expert panel convened by the National Research Council issued a report on the damaging effects of erosion-control devices on bayfronts and tidal creeks. State and local laws, in many cases, guide coastal regulators to issue numerous permits for bulkheads and other hard, erosion-control structures, the report says.

The panel calls for a new direction. Policymakers should instead revise laws and regulations to favor "more ecologically beneficial solutions that also provide shore stabilization." More people should be encouraged to protect their property by creating marshland buffers and planting marsh grasses, wherever feasible, instead of exclusively building hard erosion-control structures.

"There are an incredible number of new buildings on marsh fronts," says Riggs. "If South Carolina is into the bulkheading business, then you're going to lose a lot of salt marsh over time."

LEARNING FROM LOUISIANA?

To restore a few of south Louisiana's wetlands, engineers are re-diverting some of the Mississippi River's sediment-rich flow. This is an attempt to mimic the river's natural characteristics. In 1991 and 2002, the state of Louisiana and the federal government spent a total of $145 million on prototype projects, constructing a pair of large holes in the riverbank, which allows river flow through canals to reach wetland areas.

Perhaps by mid-century, South Carolina might have to take similar action to save salt marshes. But scientists would need to know which marshes are most vulnerable to sediment loss and sea-level rise.

Morris hopes someday to map lowcountry salt marshes to learn which wetlands would be affected first by climate change. He proposes using Light Detection and Ranging (LIDAR) technology to delineate the height of salt marshes along the entire South Carolina coast. Morris and his colleagues have already mapped North Inlet with LIDAR.

With this information, coastal managers could eventually consider adjusting river flows and diverting sediments to certain wetlands when the time comes.

"Mapping elevations would give coastal managers a heads-up and way of prioritizing their strategies for trying to preserve these marshes in the future," says Morris. "They could manipulate rivers' sediment supplies to the most vulnerable wetlands."

For thousands of years, sea level rose exclusively because of natural influences. But, over the next century, human impacts in the atmosphere and the oceans will almost inevitably push up global sea level, scientists say.

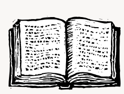
The only long-term solution to this problem would be to cut emissions of greenhouse gases, leading climate scientists say. Greater automobile fuel-efficiency standards, wind power, solar power, and clean-coal technologies might be an initial step toward slowing the acceleration of greenhouse-gas emissions over the next decade or so. Some experts argue for an expansion of nuclear power. Eventually, though, the world would need to embrace much more efficient energy technologies.

Yet no matter how quickly the global community responds to cut emissions, South Carolina coastal communities will face more flooding, more shoreline erosion, and more drowning of coastal wetlands.

Glaciers and ice sheets will continue melting, scientists say. And the ocean's deeper waters will continue to heat up. As time goes on, in lower and lower levels of the sea, the water will warm and expand, warm and expand.

Rising sea level is unavoidable, scientists say. But states, localities, and property owners can begin adapting to change by creating or improving coastal marshlands. And governments will have to better manage land uses and developments—dams, levees, bulkheads, revetments—that rob wetland-building sediments from America's coastlines.

READING AND WEB SITES



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More rapid sea-level rise predicted

Two centuries from now, Charleston, a sunken city, huddles behind a massive network of levees and seawalls. Rising sea level has long since destroyed the coast's buffer of salt marshes and barrier islands. By the year 2200, the Charleston Battery's walls have been extended and raised 20 more feet to protect historic neighborhoods, which have subsided below sea level, from battering ocean waves. Residents worry that the next hurricane surge will knock down the seawalls and drown the city forever.

A believable scenario? Yes, some scientists say.

About 18,000 years ago, the Ice Age climate began warming. Scientists say that a cyclical change in the Earth's orbit—and those of other planets—altered circulation patterns in the oceans and the atmosphere, which began a chain reaction of climate change.

At first, global warming was mild. The gigantic continental glaciers melted at the sea edges, pouring fresh water into the oceans. For the next 6,000 years, global sea level rose at a relatively calm pace overall. By the end of this period, the shoreline off Charleston was approximately 60 to 70 miles farther east than it is today.

About 14,000 years ago, global warming and glacier melting accelerated, apparently feeding on their own momentum. The Earth's climate system has a complex set of feedback loops—mechanisms that reinforce or counter the planet's warming or cooling process. During periods of rapid warming or cooling, these mechanisms can kick in, further accelerating the processes.

Nearly all feedback loops in today's climate models show that greenhouse warming stimulates even further warming.

Take the problem of disappearing Arctic sea ice. Sea ice is white, which reflects some of the sun's heat back into space, mitigating an increase in the greenhouse effect. But as the Earth's temperature rises rapidly, Arctic sea ice melts, and the result is open water, which reflects the sky and appears dark blue, absorbing more of the sun's heat. This heat absorption causes even faster melting of ice caps; and the feedback loop continues.

At the current rate of loss, Arctic sea ice will disappear by the year 2060, according to the National Snow and Ice Data Center at the University of Colorado.

A similar process occurred at the end of the last Ice Age, when global sea levels rose very rapidly, driving shorelines landward. Sea ice that connected the northern third of North America to northern Europe melted. The mile-thick glaciers that blanketed New England, New York state, most of Canada, and northern Europe disappeared. This glacier melting poured fresh water into the oceans, raising sea levels. Finally, about 4,000 years ago, the global climate more or less stabilized, closely resembling the one we have today.

The planet, in turn, has had a long period of relatively stable sea level in most locations, though overall it has continued to rise. In the early nineteenth century, global sea level began to rise somewhat faster and gained some momentum in the past hundred years.

In total, since the end of the last Ice Age, global sea level has risen about 360 feet, moving inland sometimes very slowly and steadily, sometimes explosively.

Now the overwhelming majority of climate scientists say that the Earth during this century will almost certainly have another period of relatively rapid sea level rise. This time, however, a major driving force of change will be human activity through emissions of greenhouse gases such as carbon dioxide.

MELTDOWN.
Glaciers around the world are melting at an increasing rate, pouring freshwater into the oceans. This 2003 image shows the Boulder Glacier on Mount Baker in the North Cascades of Washington. The line shows the terminus position of the glacier in 1985.
PHOTO/GLOBAL WARMING ART, www.globalwarmingart.com

EBBS & FLOWS

CNREP 2007: Challenges of Natural Resource Economics and Policy

New Orleans, Louisiana
May 20-23, 2007

This conference will provide an opportunity for government officials, resource managers, users, and residents to discuss approaches to restore coastal shellfish ecosystems through remediation and pollution abatement, habitat restoration, and stock enhancement. The conference will feature a series of invited keynote and panel presentations, case studies, and contributed oral and poster presentations. For more information, visit www.cnrep.lsu.edu.

Coastal Zone '07

Portland, Oregon
July 22-26, 2007

The biennial Coastal Zone conference, now in its fifteenth edition, is the largest international gathering of ocean and coastal management professionals in the world. Nearly 1,000 people attend, representing federal, state, and local governments, academia, nonprofit organizations, and private industry. The conference gives these attendees a platform to discuss the issues facing our world's coasts and oceans and a forum for discovering new strategies and solutions. For more information, visit www.csc.noaa.gov/cz.

National Marine Educators Association Conference 2007

Portland, Maine
July 23-27, 2007

You'll find new ideas and become part of a national network of valuable resources by attending the National Marine Educators Association Conference. NMEA 2007 is about joining together with marine educators from across the country to to celebrate the "Downeast" part of the world. For information, contact Downeast2007@gommea.org.

ATTENTION SCHOOL TEACHERS! The S.C. Sea Grant Consortium has designed supplemental classroom resources for this and past issues of *Coastal Heritage* magazine. *Coastal Heritage Curriculum Connection*, written for both middle- and high-school students, is aligned with the South Carolina state standards for the appropriate grade levels. Includes standards-based inquiry questions to lead students through explorations of the topic discussed. *Curriculum Connection* is available on-line at www.scseagrant.org/education.htm.

Subscriptions are free upon request by contacting: Annette.Dunmeyer@scseagrant.org

Sea Grant
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